Memo

Date: 8/26/98

To: Coordinating Committee, Industrial Combustion Coordinated Rulemaking

From: Combustion Turbine Work Group

RE: CTWG Pollution Prevention Considerations

The Coordinating Committee has asked the Source Work Groups to consider various concepts developed by the Pollution Prevention Sub Group. The CTWG has reviewed these concepts and have concluded the following:

- <u>Good Combustion Practices</u>
  Good combustion practices were discussed in the "RATIONALE FOR DEVELOPMENT OF MACT FLOOR FOR EXISTING COMBUSTION TURBINES, Appendix A, Operating Practices / Training Programs". This document was previously presented to the Coordinating Committee at the April 1998 CC meeting and they subsequently forwarded this to EPA for consideration. This Appendix is repeated as Appendix A to this memo. It was concluded that the turbine design practices and the high degree of automation employed to control the turbines assure that combustion turbines intrinsically utilize good combustion practices.

- <u>Operator Training</u>
  Operator training was also discussed in the "RATIONALE FOR DEVELOPMENT OF MACT FLOOR FOR EXISTING COMBUSTION TURBINES, Appendix A, Operating Practices / Training Programs". The CTWG concluded that operator training would not be effective as a means to reduce HAPs emissions due primarily to the high degree of automation of combustion turbines.

- <u>P2 Metrics</u>
  P2 Metrics would not apply if there were no numeric standard. If there was a numerical standard, the CTWG suggests that it be based on mass of HAP per unit of energy consumed with an efficiency correction similar to NSPS Subpart GG for NOx whereby an efficiency multiplier for turbines over 25% thermal efficiency is provided. This effectively makes the standard an output based standard. The rationale for taking this indirect approach to establishing an output based standard is that in many cases turbines have no means for direct measurement of output power.

- <u>P2 MACT options (alternative compliance)</u>
  The CTWG supports this concept as long as the options are not mandatory. Until such time as EPA develops prescriptive alternative compliance standards, the CTWG can not provide specific comments to such an approach.

- <u>Waste accounting and record-keeping</u>
  The CTWG considers this not to be applicable to combustion turbines since they do not burn solid or waste fuels.

- <u>Work practice</u>
  Work practice was also discussed in the “RATIONALE FOR DEVELOPMENT OF MACT FLOOR FOR EXISTING COMBUSTION TURBINES, Appendix A, Operating Practices / Training Programs”. Again, due to the high degree of automation in combustion turbines, the CTWG could not identify any appropriate work practice standards. Also O&M procedures established by manufacturers and followed by owner/operators are designed to improve reliability of the turbine and the CTWG concluded that these procedures would not be effective at reducing HAPs.

- <u>Fuel constituent standards</u>
  Fuel constituent considerations for combustion turbines is discussed in Appendix B, “Fuel Quality”. Also the P2 Sub Group recommendations don’t identify areas where fuel constituent standards would apply to combustion turbines.

- <u>Fuel De Minimus</u>
  The P2 Sub Group considers these de minimus standards not to apply to natural gas and distillate oil fuels and therefore such limits would not apply to the large majority of combustion turbines.

- <u>P2 Planning</u>
  The CTWG reviewed the applicability of P2 planning to combustion turbines. For combustion turbines specific application requirements limits options available for the owners/operators. Strong market place incentives are already in place to optimize efficiency and the P2 planning concepts are already a part of established design/ engineering criteria as discussed in Appendix C, “Combustion Turbine Thermal Efficiency”. Requirements such as a planning process and the periodic review process would not provide any significant benefit and would be burdensome to owner/operators as well as to regulatory agencies.

Appendix A

OPERATING PRACTICES / TRAINING PROGRAMS

Objective

This analysis seeks to determine if specific operating practices and/or operator training programs have the potential to reduce HAP emissions from combustion turbines and to propose such operating practices/training programs, if any, for inclusion in the MACT standard for combustion turbines. Rather than discussing generalities or specific capital features such as adding recuperators, the focus will be on specific operating practices/training programs that can be implemented on combustion turbines to reduce HAP emissions.

Background

Proper maintenance and upkeep of a turbine will help ensure optimum performance over its lifetime. Manufacturers recommend operation and maintenance (O&M) procedures to establish the parameters under which their warranty for the equipment would be valid. They are designed to avoid equipment damage rather than to minimize emissions, recognizing however, that proper maintenance will usually maintain good efficiency or improve poor efficiency. These O&M procedures contain sections on preventive maintenance and corrective maintenance. While owners/operators may customize these manufacturer-recommended O&M procedures due to updated information or to suit site-specific conditions, such as extreme ambient temperature fluctuations or remote automated operations, ignoring or neglecting service/maintenance procedures will have an adverse impact on the performance and life of the turbine.

Recognizing its importance to the long-term well-being of the equipment and to resulting air emissions, some state and local air permits contain language:

(1) specifying that O&M manuals need to be developed, maintained on-site or at the nearest manned site and made available for inspection upon request; and

(2) requiring periodic certifications, under Title V, that the O&M procedures are being followed and kept current.

The ICCR database contains emissions from a variety of combustion turbines. Emissions vary by one to two orders of magnitude, with no discernible pattern or reason. There is no process or operating information in the database that seems to be able to explain the inherent variation or its cause. HAPs emissions are either products of incomplete combustion (PICs) or they may be reaction products from metallic elements in the fuel. The combustion characteristics and degree of completeness of combustion are determined by several factors including type of combustor, firing temperature, residence time, stoichiometry, combustion chamber configuration, and whether water/steam injection is used for NOx control.

Turbine Applications

Turbines are used in the utility power generation industry, cogeneration applications, industrial mechanical-drive and pipeline applications, offshore and marine applications. Cogeneration applications are generally base-load applications, while utility power generation will include base-load and peaking units. Industrial mechanical-drive and pipeline applications are generally load-following applications, where the output load sends signals to the control system to regulate the fuel accordingly.

Design Aspects

Combustion turbines operate on the principle of volumetric expansion of air at very high rotational speeds. The expansion of heated air occurs through and across stationary nozzles and moving blades, machined with great precision. The very high speeds and close tolerances of centrifugal machinery are directly proportional to efficiency. Speeds are so high in fact, that turbines are heavily instrumented with both control, safety and diagnostic features that sense and respond much faster than a human being might. Combustion turbines have relatively few contacting parts (compared to a reciprocating engine, for example) and are highly reliable.

The turbine design is based on a thermodynamic cycle and an aerodynamic flow path. This establishes the point of maximum efficiency. A turbine's performance can then be represented by a set of performance curves, relating output power to ambient temperature, fuel flow, exhaust mass flow, exhaust temperature, and inlet and exhaust duct pressure losses. An altitude correction factor will account for operation at elevations other than sea-level. Once these parameters are established by the manufacturer's design, the unit's control system package regulates operation along these curves, with very little active operator involvement. Since operation of a turbine outside of the control system defined boundaries could lead to premature mechanical failures, turbine manufacturers have adopted control system design practices that assure very high reliability for the controls.

Turbine Operation

Although there are design variations, the start sequence generally starts with the pre-lube cycle. Following that the starter is engaged and rotation of the turbine begins. After attaining the minimum speed and upon completion of the purge cycle to remove any fumes that might cause premature explosions and that can impede ignition, ignition occurs. As fuel is increased, the turbine speed increases at an automatically controlled rate and at a specified design speed, the starter will be disengaged. The unit then accelerates to design speed and becomes self-sustaining. Any malfunction in the system will cause the control system to stop the fuel feed, thereby shutting down the system. Speed or power is then changed by signals to the throttle valve through a governor or actuator. During operation, the unit control system continuously maintains cycle parameters within predetermined constraints set by the manufacturer as part of the turbine design. The shutdown procedure is initiated when the run circuits are de-energized and the fuel feed is reduced at a predetermined rate and stopped, thereby causing the turbine to coast to a stop after a cool-down cycle. In some applications, such as interstate pipelines, the start/shutdown sequence is automated and is generally initiated remotely from a central control room for the entire system of turbines along the pipeline. Once a unit comes on line, the automated control system takes over and operates the unit at design load with minimal involvement and oversight from manual systems.

In all the applications, the unit control system generally regulates fuel throttle to maintain acceptable firing temperature and speed follows. The control system provides warning and/or automatic shutdown signals in the event of an undesirable operating condition. Under normal operating conditions, there is little operator involvement in the operation of the combustion turbine.

Operating Practices

Under the topic of operating practices, the Pollution Prevention subgroup recommends:

(1) operating practices – documentation of operating procedures, including startup, shutdown and malfunction plans, and maintenance of operating logs;

(2) maintenance knowledge – operator training;

(3) maintenance practices – documentation of maintenance procedures; and

(4) monitoring fuel quality.

The following discussion addresses each of these topic areas as they pertain to combustion turbines.

1. Operating Practices:

As stated earlier, some state and local air permits often specify that O&M manuals be followed and require that such manuals be kept on-site and made available for inspection. Recognizing the inherent design variations and the influence of site-specific conditions, the owner/operator is given the flexibility in some state permits to develop site and unit-specific O&M procedures. Other regulatory requirements also specify the use and maintenance of documented operating procedures. The MACT standard General Provisions (40 CFR Part 63) specify the use of startup/shutdown procedures to help maintain compliance with a MACT standard. States such as Texas, Oregon, Washington and Idaho, specify the use of written startup/shutdown procedures to minimize emissions if there is the potential for excess emissions during such transient conditions. The requirement to maintain logs are specified by the monitoring, record keeping and reporting requirements under the 40 CFR Part 70 (Title V operating permit) regulation. (Most turbine facilities are probably major sources of criteria pollutants and hence fall under Title V.) Other regulatory agencies, such as the Department of Transportation (DOT), specify detailed written operating and maintenance procedures for interstate pipelines. These are pre-existing requirements and new, additional regulation is not necessary for operators to follow an O&M procedure or plan.

O&M procedures are established by manufacturers and followed by owner/operators to improve the reliability of the turbine and avoid equipment damage. There is no evidence that following such procedures will result in a reduction of HAP emissions which depend on the degree or completeness of combustion, combustion characteristics and the design parameters. The CTWG believes that these O&M practices are followed by all turbines in the inventory database. Therefore, there is no evidence to suggest that HAP emissions from the highest-emitting unit in the ICCR database was caused by improper O&M practices or that the HAPs can be reduced by specifying a more detailed or exhaustive/comprehensive O&M procedure for that unit.

2. Maintenance Knowledge / Operator Training

Combustion turbines are a sophisticated reliable technology, designed for remote, automated operations with minimal operator involvement for routine operations. Unlike process heaters, boilers and IC engines, there is no provision for the turbine operator to change operating parameters, such as adjust the air to fuel ratio or the spark timing. Once the manufacturer commissions a turbine in the field, the operator makes no changes to key design operating parameters. The manufacturer may inspect and confirm the key design parameters at the time of a turbine overhaul, but the operator does not make design changes on his/her own initiative and does not seek to operate the unit outside the design specifications.

Operators, as part of their internal O&M procedures, also specify training and/or qualification requirements from a performance, reliability, service/maintenance, manufacturers warranty requirement, and a safety perspective. Established company training programs also specify the ground-rules by which an apprentice advances to a mechanic or a technician level, a prerequisite to operating multi-million dollar equipment. Other programs, such as OSHA and Process Safety Management (PSM), address operator training programs and requirements. For example, PSM specifically is triggered if more than 10,000 pounds of fuel in a covered process is stored on site. The risk management program under section 112(r) of the CAAA establishes thresholds for certain chemicals, and specifies training on accident prevention and release response procedures. Owners and operators in the spirit of efficient training and saving resources are taking advantage of combining mandatory PSM training with general operator training. Inter-state pipelines are subject to DOT regulations that specify prescriptive operator training requirements. New, additional regulatory language in a combustion turbine MACT is therefore not necessary to prompt turbine owner/operators to protect their significant capital investment by ensuring that their operators are properly and adequately trained.

As was the case with operating practices, there is no evidence to suggest that HAP emissions from the highest-emitting unit in the ICCR database were caused by improper training programs or that the HAPs could be reduced by specifying more operator training. Design parameters establish the emissions profile and operator training programs cannot change the design emissions profile. The inherent emissions variability, caused by design variations, cannot be avoided or eliminated by operator training programs.

3. Maintenance Practices:

The discussion of O&M practices in the Operating Practices section deals with maintenance practices also. Owner/operators follow manufacturer-recommended or customized (to account for unit- and site-specific characteristics) O&M procedures and practices to ensure reliable performance of their turbines. Given the sizable capital investment, the owner/operators have a vested business interest in the longevity and continued performance of the turbine. Additionally, air permits generally specify that the equipment be operated and maintained properly to ensure its proper functioning.

Again, there is no evidence to suggest that HAP emissions from the highest-emitting unit in the ICCR database were caused by improper maintenance procedures. It is also not evident that specifying additional maintenance procedures would have reduced the HAP emissions. The inherent emissions variability is a function of design and combustion characteristics, and does not appear to be a function of maintenance procedures.

4. Fuel Quality:

The fuel quality, whether in terms of superheat or dewpoint for gaseous fuels, and/or the presence of entrained impurities, will be specified by the manufacturer and continued use of fuel outside manufacturer's specifications will likely result in unit malfunction and/or degradation of performance. Some regulations, such as the fuel sulfur requirement in the NSPS regulation, specify fuel constituent limits. The owner/operator's vested interest in protecting his/her capital investment will dictate that particular attention will be paid to the fuel quality and any resulting lack-of-performance issues.

Manufacturers generally provide fuel specifications for liquid fuels, especially with regards to metals. Knock-out pots and filters are used in some cases to remove entrained liquids and other impurities. Both gas-fired and liquid-fired combustion turbines showed high variability of HAP emissions, but fuel quality does not explain the inherent emissions variability seen in the data.

Some other parameters with the potential to affect turbine emissions are considered below.

Air to Fuel Ratio: The air-to-fuel ratio, a design criterion, is specified by the performance curves referred to earlier and any change to the relationship designed by the manufacturer is not possible without significant change to the hardware and control system. A delicate balance of air to fuel ratio has to be maintained to sustain proper combustion. Manufacturers are now using staged combustion and/or variable geometry concepts to achieve stable combustion while minimizing criteria pollutants. Variable geometry combined with pre-mixing air and fuel is now being used to optimize combustion conditions for low emissions, but this is not a feature that an owner/operator can modify at his/her discretion. Inlet guide vane (IGV) settings (controlling the total air flow to maintain air/fuel ratio at the design condition over an extended range) are generally established by the manufacturer upon installation, and owner/operators do not modify these settings after startup on their own. Not only is inlet air used for combustion, but a major portion of the air is also used for cooling purposes and altering the proportion beyond design criteria could have negative impacts on internal metallurgy (e.g., creep crack, oxidation, etc.). The data in the emissions database does not show a direct relationship between HAP emissions and air to fuel ratios. Since air to fuel ratios are set by design considerations, with no provision for operator modification, this is not a practical operating technique to control HAP emissions from combustion turbines.

Water/Steam and Ammonia Injection: Where there is water/steam or ammonia injection, air permits require that the injection rate be monitored. The Part 60 NSPS regulation also requires continuous monitoring for such units. This is a pre-existing requirement and therefore does not need to be added to a MACT regulation.

Monitoring Temperature Profiles: For certain turbine types, (e.g., can annular combustor types), monitoring of the combustion temperature profiles will provide an indication of proper operation. Any clogging or abnormality in the fuel feed system would result in an irregular temperature profile and lower power output. On many turbines of these types, the unit control package monitors the temperature profile and triggers system alarms or corrective actions (e.g., automatic control system correction in fuel flow split between the primary and secondary stages in a lean pre-mix combustor) in the event of abnormalities or deviations outside pre-set ranges. Even without monitoring the temperature profile, which is not the case, reductions in power output will alert and flag the operator to a potential abnormality or malfunction within the system. Higher fuel costs to generate the same power output will also prompt corrective action.

Conclusion

Examination of the database did not reveal specific O&M practices or operator training programs that could explain or remove the inherent emissions variability. It was not possible to identify any viable specific operating practice or training program to reduce HAP emissions across the various fuels, makes, models, and sizes of combustion turbines. It does not appear that any specific operating practice or training program would eliminate the inherent emission variation among the different makes and models and cause a general reduction in the level of HAP emissions. The emissions variability in the database indicates that HAP emissions are a function of equipment and design constraints and limitations, and not a function of O&M practices.

O&M procedures are widely used by industry and by the manufacturers to formalize operation and maintenance activities. Additionally, programs such as OSHA, PSM and state/local air permits establish O&M practices and operator training requirements. Given the pre-existing programs, new or additional requirements are not necessary to ensure proper operation and maintenance of turbines.

O&M procedures established by manufacturers and followed by owner/operators are designed to improve the reliability of the turbine and avoid equipment damage. There is no evidence that following such procedures will result in a reduction of HAP emissions, which instead depend on the degree or completeness of combustion, combustion characteristics and the design parameters. There is no evidence to suggest that HAP emissions from the highest-emitting unit in the ICCR database was caused by improper O&M practices, or that the HAPs could have been reduced by specifying a more detailed or exhaustive/comprehensive O&M procedure for that unit.

Appendix B

Fuel Quality

In addition to incomplete combustion, contaminants in the fuel stream could also lead to HAP emissions. Other potential sources of metal emissions include ambient air, equipment surfaces, and wet seal and other oil leaks. However based on a simple mass balance and the experience that observable metal losses are not seen on equipment surfaces, the CTWG does not believe that equipment surfaces could be an appreciable source of metal emissions.

Generally, manufacturers specify fuel quality standards, particularly in terms of metal content, for liquid fuels. Liquid fuels fall into two classifications, distillates (No. 2 distillate oil) and ash-forming oils (residual oils). While distillates generally contain a lower level of metal contaminants, the heavy residual oils often contain higher levels of trace metal contaminants and fuel treatment is, therefore, required to remove or modify the harmful corrosive and fouling effects of these contaminants. The trace metal contaminants of concern include sodium, potassium, calcium, lead, vanadium and magnesium. Typically, manufacturers specify acceptable levels of these harmful contaminants in the fuel stream to prolong the useful life of the equipment and adherence to these fuel specifications will be sufficient to address issues regarding fuel quality.

Metals and other harmful contaminants are generally not present in gaseous fuels and, therefore, are not a concern. EPA , in its "Mercury Study, Report to Congress" dated December 1997, lists various sources of mercury. Table 3-1 of the report shows that anthropogenic combustion sources contribute about 86.9 percent to the total nation-wide mercury emissions inventory. Of this, about 32.8 percent comes from utility boilers and the contribution from natural gas-fired boilers is less than 0.1 percent of the total (0.002 t/y). The list does not include turbines and does not identify natural gas fuel as a significant contributor to the mercury problem.

A sample fuel analysis done by GRI, GRI-95/0200, "Gas-Fired Boiler and Turbine Air Toxics Summary Report", on natural gas fuel, shows that most of the metals are below detection limits in natural gas fuel. Mercury has been measured in the range of 0.0006 $lb/10^{12}$ Btu to 0.0013 $lb/10^{12}$ Btu. Other measurements of mercury in natural gas fuel indicate levels of up to 0.0026 $lb/10^{12}$ Btu (1 ug/m3 = 0.06 $lb/10^{12}$ Btu). These measurements indicate that mercury is not present in natural gas fuel in significant quantities.

A majority of well-head gas, following removal of liquid and vapor phase produced water if required, is placed directly into interstate pipeline transmission systems. Only a few gas fields have been found to contain mercury at concentrations higher than the trace amounts noted above.

The measured mercury levels at these gas fields are:

Location	Range (ug/m^3)	Source
Gulf of Mexico	0.02-0.40	GRI (Mercury Removal Process Design and Engineering)
Overthrust Belt	5-15	GRI (report cited above)
WY "well-head gas"	8-24	Aluminum Coldboxes, technical paper presented at the 75th annual GPA convention)

Any mercury present in well-head gas will mix with other gas in the pipeline as it travels hundreds and thousands of miles to the downstream markets and will be diluted to insignificant levels.

Chromium has not been detected in natural gas fuel; no published source test data has been found showing chromium in natural gas fuel. The currently available literature showing emission factors for chromium in natural gas, are based on assuming 50 percent of the detection level, not on actual measurements. The GRI report, GRI-95/0201, "Gas PISCES Project Screening Health Risk Assessment", discusses chromium emissions from different fuel types. Because chromium was not found in either natural gas fuel or ambient air, the report concludes that any chromium in exhaust gas is probably from the unit surfaces, not from the natural gas fuel. However, manufacturers report no measurable erosion of metal from component parts of Combustion Turbines.

These GRI reports find that health impacts from combustion of natural gas fuel are below the established significance levels and, therefore, not a cause for concern. EPA, in its February 1998 Utility Air Toxics Study final report to Congress, also concludes that HAP emissions from natural gas combustion are not significant enough to warrant further consideration.

Appendix C

Combustion Turbine Thermal Efficiency

The ICCR Pollution Prevention Sub Group had identified efficiency improvements as one means to prevent pollution and to consider efficiency within the MACT regulations. Motivated by competitive market forces, gas turbine design advancements continue to improve thermal efficiency. The thermal efficiency can vary widely depending on the specific design and cycle used. However, requirements for the specific type of application dictate the most technically feasible and economically viable choice of design. Because of this, the ICCR Combustion Turbine Work Group (CTWG) does not recommend that MACT regulations attempt to develop language to specify efficiency requirements for combustion turbines. However efficiency losses associated with various control devices should be considered in "Above the Floor" evaluations to develop the MACT regulation.

Discussion

The CTWG has reviewed the impact of improved thermal efficiency in gas turbine systems on HAPs emissions. The ICCR Pollution Prevention Task Group recommended that the Work Groups consider efficiency improvement as a possible means of pollution prevention. Conversely, reductions in thermal efficiency due to added pressure drop that would result from the addition of emission control systems, such as oxidation catalysts, were also considered by the CTWG. This section documents the results of the CTWG review.

Effect of Thermal Cycle on Efficiency and HAPs Implications

Several fundamental approaches are used to increase gas turbine efficiency. The firing temperature (turbine inlet temperature) is directly related to the efficiency that can be theoretically achieved. Firing temperature increases have been accompanied by increases in turbine pressure ratio that also increases the thermal efficiency. Continued advancements in materials and component cooling technology have allowed the higher firing temperatures and consequently higher thermal efficiencies. (Note: In this discussion thermal efficiency is defined as the ratio of the useful power and heat energy output of the system divided by the fuel consumption on a lower heating value basis.) Turbine designers have also been able to reduce leakage losses and improve component aerodynamic efficiency, both of which lead to greater system thermal efficiency.

Still another approach to improving system thermal efficiency is to recover and utilize energy that would normally be wasted in the turbine exhaust. Regeneration, cogeneration, and combined cycle systems recover this energy to improve the system thermal efficiency while simple-cycle systems do not. These efficiency improvements are in addition to those improvements resulting from the turbine design advancements discussed in the previous paragraph.

The increased firing temperatures that have led to better thermal efficiencies also lead to more complete combustion in conventional combustion systems. However the increased firing temperature also tends to increase NOx formation. Consequently NOx reduction technologies such as wet controls, (i.e. steam/water injection) lean-premix combustion, and selective catalytic reduction systems have been developed and catalytic combustion is being developed.

Some of the NOx control techniques adversely impact gas turbine thermal efficiency. For instance, catalytic emission controls in the exhaust path of the turbine impose a pressure drop penalty on the turbine that reduces the efficiency. For cases where water injection is employed without waste heat recovery, thermal efficiency is reduced because additional fuel is required to vaporize the water that is injected into the combustor. In cases where either steam or water is injected for NOx control, there may be an increase in CO from the gas turbine due to a decrease in combustion efficiency. The regulatory response in some cases has been to require a CO oxidation catalyst and this reduces the overall thermal efficiency even further due to the additional back pressure.

Simple cycle turbines range from 15 to 42% thermal efficiency. Most turbines sold today tend to be between 28 and 42% thermal efficiency. The older and smaller units tend to have lower simple cycle efficiency in the 15 to 25% range. With advances in materials and cooling technology, the firing temperature now exceed 2600F in the most advanced models and this has resulted in thermal efficiency as high as 42%.[(1)] Competitive pressures in the market place are largely responsible for these advances and the trend is expected to continue driving efficiencies higher and NOx lower. Despite these notable advances in thermal efficiency there is still a market for the lower firing temperature, lower efficiency turbines for situations where reliability is a higher need than efficiency. An emergency power turbine is one example of such a situation.

Simple cycle turbines are used in a number of industrial and utility applications. In peaking and emergency electrical power applications they are utilized for short, intermittent periods of time. For these turbines the extra expense of recovering energy from the exhaust stack is not warranted (from either an economic, energy conservation, or emission reduction perspective) based on the infrequency of use and low hours of operation. Furthermore, the complexity of such systems conflicts with the requirement that these turbines start rapidly and reliably when needed. Most heat recovery systems require slow startup (from thirty minutes to several hours dependent on the application), which is incompatible with the mission of an emergency or peaking unit.

Many simple cycle turbines are used in mechanical drive service, primarily to power pumps and compressors in the oil and gas industries. Mechanical drive turbines used on gas pipelines and in oil and gas production generally do not utilize waste heat recovery systems. This is because many of these are at remote sites where there is no need for a source of heat energy and/or there is no access to the electric power grid. Without a ready market (internally or externally) for this energy it can not be recovered. Even if the installation were near a transmission line, the cost and complexity of adding a waste heat recovery system to these mechanical drive turbines (which generally are less than 25,000 HP) may not be economically attractive or operationally viable to their owners.

Regenerative cycle combustion turbines recover heat from the exhaust to preheat the compressed air delivered to the combustor. The regenerated turbines have efficiencies in the range of 34% to 36%.[(2)] This type of cycle is limited to low pressure ratio turbines because higher pressure ratio turbines have compressor delivery temperatures greater than the turbine exhaust temperatures and consequently exhaust heat can not be transferred to the compressed air. The trend in turbine design is toward higher pressure ratios to achieve higher efficiency and higher power density. This trend combined with the higher firing temperatures of the more modern turbine designs, has resulted in simple cycle turbines approaching, and in some cases surpassing, the efficiency of the regenerated turbines. Because of this trend, very few regenerative cycle turbines are currently being sold. In addition, a regenerative turbine has very little recoverable heat.

Gas turbines in cogeneration cycles recover waste heat from the exhaust by exchanging the heat with water to make steam, or with some other heat transfer medium to provide thermal energy to an industrial need. These systems may have thermal efficiencies as high as 84%.[3] The amount of energy that may be recovered is limited because exhaust temperatures must not normally be allowed to go below the moisture dew point to prevent corrosion of the exhaust system components. Other factors, which may limit heat recovery, are the energy need and temperature level required by the process that the cycle supply. Dependent on process needs, lower temperature energy may not be readily useable, which would also limit energy recovery.

Cogeneration can only be utilized economically when the turbine can be paired with an industrial requirement for thermal energy. These systems are often found in refineries, oil and gas production, chemical, food processing, pharmaceutical, building materials, or paper plants. Some systems require more thermal energy than can be provided by the turbine and in such cases supplemental firing (i.e., duct burners) may be employed to satisfy the need. These systems have become very popular since the Public Utility Regulatory Policies Act of 1978 (PURPA) as cogenerators may sell excess power into the electrical grid. There is a strong economic incentive for industries to utilize the gas turbine waste heat in a cogeneration system and to sell excess power.

The combined cycle is an extension of the cogeneration cycle. In a combined cycle the gas turbine exhaust waste heat is captured in a heat recovery steam generator (HRSG) to generate steam, that drives a steam turbine, that drives another electrical generator. The thermal efficiency of combined cycle plants range from 38% to 60%.[4] The combined cycle system's sole product is electricity and, as such, is used widely by electric utilities and independent power producers.

Due to the startup fuel requirements, cogeneration and combined cycles are not appropriate for applications where there are frequent starts and few hours of operation (such as emergency service, peaking, and many pipeline applications). Because the waste heat recovery boiler and steam turbine are slow to come to operating temperatures, these applications can burn more fuel during the warm-up than fuel savings that might result from the higher efficiency that the systems would achieve in continuous operation.

Combined cycle systems are much more complex than the other cycles discussed. In addition to the combustion turbine, a heat recovery steam generator, steam turbine, steam and water piping, and water treatment facilities are required. The amount of area required for the plant, the capital costs, and the complexity of operation are all much greater than would be required for a simple cycle turbine. These are other reason that combined cycle plants are not appropriate for all applications.

Summary

As can be seen from the previous discussion, gas turbine thermal efficiencies vary widely dependent on the particular cycle configuration and turbine model. However from a practical standpoint most applications are driven toward a specific cycle.

- For emergency or peaking service, where reliability is critical and efficiency not as important because the units are not operating for long periods of time, a simple cycle turbine is the best choice.

- Simple cycle turbines or regenerative cycle turbines will also be used for mechanical drive applications in remote sites that have no need for waste heat or electrical energy. If mechanical drive turbines are operated for a major portion of time, then fuel costs will provide a very strong incentive for the operator to select the more efficient models. Fortunately, advancements in turbine designs continue to bring more efficient turbines into the market.

- Many large industrial facilities that can use thermal energy have employed cogeneration cycle gas turbines to supply the thermal needs of the plant. But only facilities that have very specific needs for thermal energy at temperatures that can be supplied by a combustion turbine can make use of this cycle. Users that have no process need for thermal energy can not make use of the waste heat in this manner.

- Combined cycle gas turbines provide a means of utilizing the exhaust heat when the end product is electrical power. These are generally used by utilities, independent power producers or for on-site power. Since electrical generation costs are heavily dependent on the cost of fuel, electrical generators tend to select these more efficient cycles over the simple cycle for base loaded operation.

The ICCR Pollution Prevention Sub Group asked the Work Groups to consider efficiency as applicable to the MACT regulations. For MACT, one would need to show the effective HAPs reduction resulting from these technologies. While one might assume that a reduction in fuel use would be directly related to a reduction in HAPs, it would be very difficult to prove this from the data at hand. The ICCR gas turbine emissions database shows HAPs emissions that vary over several orders of magnitude for various sites. However, competitive turbine models vary in fuel needs by less than 20% for a particular type of application.

Furthermore, as described above the various types of turbine cycles usually are determined by the nature of the application. So while there are very efficient cogeneration cycles in use, they may not be appropriate for use by a pipeline turbine operating at a remote site (for example). Also as previously explained, users of combustion turbines already have a strong economic incentive to select the most efficient turbine that satisfies their requirements. Therefore, it is not recommended that MACT regulations attempt to develop language to specify efficiency requirements for gas turbines. The existing economic incentives are strong enough to encourage owner/operators to use the most efficient technology practical.

Effect of Add-on Exhaust Controls on Efficiency

Several catalyst technologies have been considered by the CTWG for possible control of organic HAPs from gas turbines. Such technologies impose a thermal efficiency penalty of around 0.175 % per inch of H_2O of exhaust back pressure.[5] Typical CO oxidation catalysts have pressure losses around 1 - 1.5 inches W.G. (when new and clean)[6] and this results in a loss of system thermal efficiency of 0.175 - 0.263%. Additional losses for transition ducting are not accounted for in these numbers and these system losses could be of the same magnitude to the catalyst losses. Pressure losses and the resulting thermal efficiency penalty can be expected to be higher for retrofits in space constrained applications.

The concentration of organic HAPs into the oxidation catalyst will also be an important factor in the amount of pressure loss. The pressure loss through an exhaust catalyst is dependent on the flow area. An open matrix with low surface area will have a smaller loss than a high-density matrix with higher surface area. The catalytic reaction only occurs at the surface of the catalyst and hence to reduce a low HAP value even lower requires a very high density of cells with very high surface area. Therefore pressure losses for a HAPs oxidation catalyst may be much higher than losses for the typical CO oxidation catalyst discussed above. The resulting thermal efficiency loss should be considered when assessing the cost effectiveness of "Above the Floor Alternatives" for existing and new turbines.

References:
(1) Gas Turbine World 1997 Handbook, Volume 18, Pages 40-51 and Pages 68 - 75, Electrical Power, Mechanical Drive Statistics.
(2) Gas Turbine World 1997 Handbook, Volume 18, Page 70, Selected statistics for regenerative cycle turbines.
(3) Cogeneration Application Considerations, R.W. Fisk and R.L. VanHousen, 39th GE Turbine State of the Art Technology Seminar, August 1996, GER-3430F
(4) Gas Turbine World 1997 Handbook, Volume 18, Pages 54 - 63, Combined Cycle Statistics
(5) Gas Turbine World 1997 Handbook, Volume 18, Page 120, Waste Heat Recovery Steam curves with unfired HRSGs
(6) ENGELHARD Letter of April 27, 1998 from Fred A. Booth to S.A.Allen, Phone (410) 569-0297